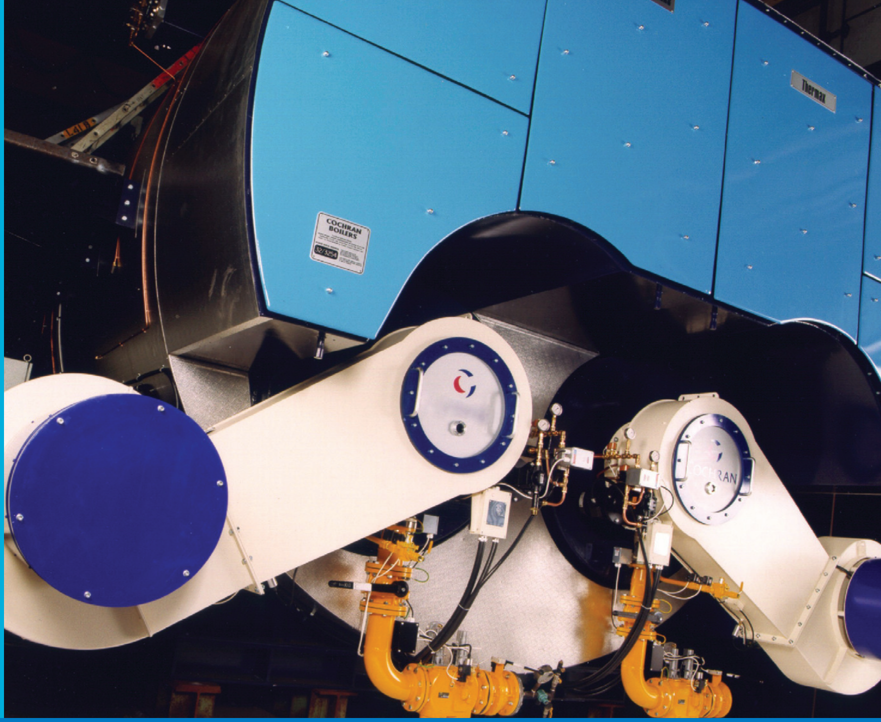


GPG369

Good Practice Guide

Energy efficient operation of boilers

ACTIONenergy

From the Carbon Trust

Contents

Action Energy gratefully acknowledges Spirax Sarco, BIB Cochran and all other organisations that contributed to this guide.

1 Introduction

This guide provides users and owners of steam boiler plant with practical advice on how to optimise energy efficiency through proper operation of the boiler and its associated systems. The guide is designed for use by energy managers, engineering staff and maintenance teams, involved in the day-to-day operation of industrial steam boiler plant with a thermal output in the range 5MW to 30MW. The information could also be used to specify the standard of maintenance requirements for those who decide to outsource their boiler management.

Steam is used throughout industry, commerce and the public sector for a wide range of process and space heating requirements, and can represent a significant proportion of an organisation's energy costs. It is therefore important for owners and operators of steam boilers to ensure that the plant is designed, installed, commissioned and operated with due regard to energy efficiency as well as safety and reliability. This guide provides an introduction to the key issues that users and operators should consider. It deals mainly with shell boilers, as most existing UK boiler plant is based on this type of boiler design, although much of the advice is applicable to other types of boilers.

Potential for energy savings

Energy savings of 10% can generally be achieved by improving the design and operation of boilers and their associated distribution systems. A UK survey of 300 boilers over 100 sites showed that average savings of 7% are possible by improving the efficiency of steam generation; further savings can be achieved by applying energy efficiency measures to steam distribution. For more information about these topics, see **ECG066 Steam generation costs** and **ECG092 Steam distribution costs**[1].

The efficiency of a system can be improved by effective implementation of a selection of the measures presented in this guide. Opportunities for energy savings are shown in Table 1 (the measures are not always cumulative and may be interdependent). The appendix contains an example calculation of the energy and carbon savings obtained by improving boiler efficiency.

Operating costs are minimised by running boiler plant at high boiler efficiency. This guide examines the various potential sources of lost efficiency and explains how they can be identified and reduced.

Significant opportunities exist to achieve energy savings with short paybacks using proven technology. These opportunities are often overlooked and this guide aims to encourage owners and operators to:

- Review how their boiler plant is operated and maintained
- Adopt the best energy saving practices, procedures and technical solutions.

[1] These and other Action Energy publications listed in this guide can be obtained free of charge by calling the helpline on 0800 58 57 94 or by visiting www.actionenergy.org.uk.

Table 1 Energy saving opportunities

Technique/method	Energy saving potential	Relevant section of the guide
Operation and maintenance of boilers	Up to 5%	2
Water treatment and boiler water conditioning	Up to 2%	3
Total dissolved solids (TDS) control and boiler blowdown	Up to 2%	4
Blowdown heat recovery	Up to 3.75%	5
Boiler and burner management systems, digital combustion controls and oxygen trim	Up to 5%	6
Variable speed drives (VSDs) for combustion air fans	*	7
Flue gas shut-off dampers	Up to 1%	8
Economisers	Up to 5%	9
Combustion air preheating	Up to 2%	10

* It is not usual to relate this method to the total boiler plant efficiency, but to a saving with respect to the electrical consumption of the boiler combustion air fan.

Types of boiler

In general terms, a boiler is a device that converts the chemical energy of a fuel (e.g. gas, coal or oil) into a useful heat output, such as steam or hot water. Typically boilers heat water or a thermal fluid (e.g. mineral oil), or generate steam.

In most cases, boilers have a furnace chamber, where heat is largely transferred directly from the flame by radiation, and flue gas passages, where heat is transferred primarily by convection.

There are many different types of boiler design and construction, but all boilers are derivatives of two basic types:

- The water tube type, where water is contained in tubes and hot combustion gases pass around them
- The shell or fire-tube type, where combustion gases pass down a furnace tube and subsequent tube bundles immersed below water level within the shell. Most existing UK boiler plant is based on this type of boiler design.

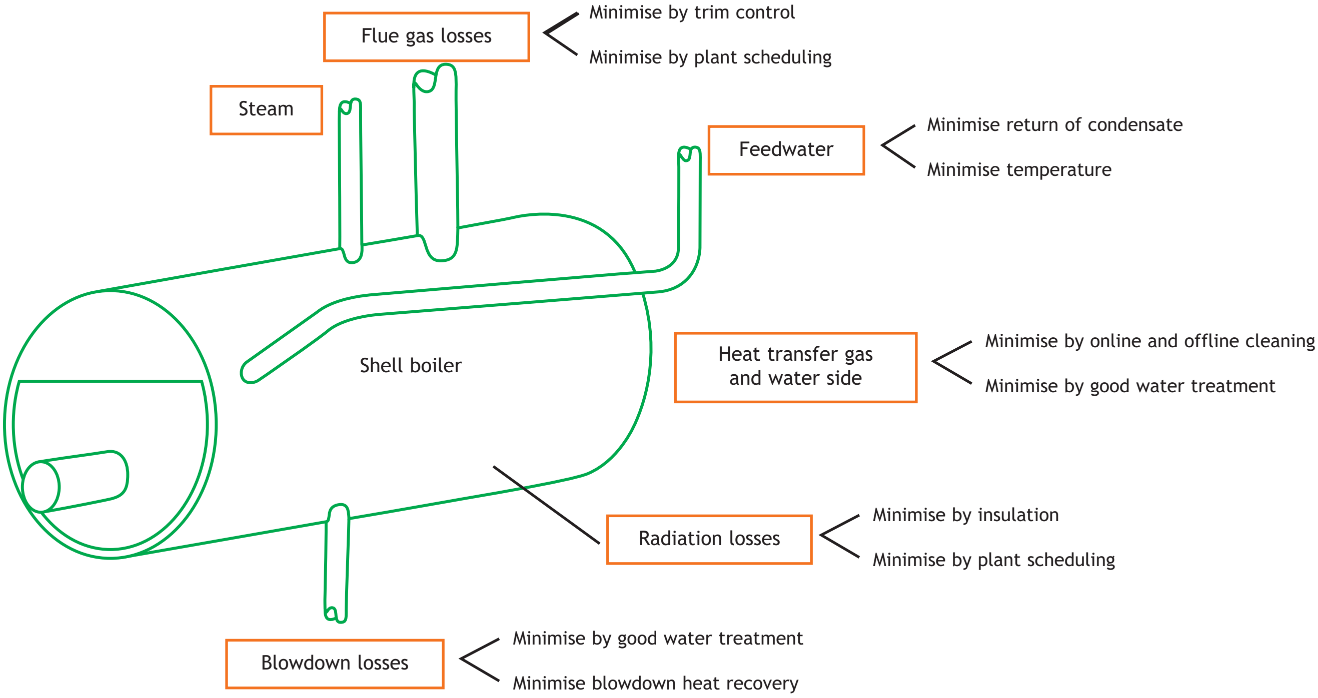
Steam and pressurised hot water boiler plants in industry range in duty from 100kW to over 30MW. This guide provides information directly relevant to shell boilers generating steam in the middle of this duty range, although much of the advice is also relevant to other boiler types and duties.

The mechanisms for handling and burning fuel differ markedly for solid, liquid and gaseous fuels and the design of a shell boiler depends on the intended fuel type(s). However, this guide does not distinguish between fuel types.

Converting a boiler to run on a cheaper or more readily available fuel may require significant modification to provide safe and efficient operation. Multi-pass shell boilers may be designed for firing using any of the conventional fuels or may be suitable for dual-fuel operation (e.g. interruptible gas and oil back-up).

When operated correctly, all modern steam boilers are capable of achieving an efficiency of around 80% (based on the gross calorific value of the fuel). Higher efficiencies are possible for condensing gas boilers and for plant fitted with economisers (see section 9), but many older steam boilers will be unable to operate at these levels. Boilers should have an operating efficiency of over 75% (based on gross calorific value) and, if they do not, action should be taken to achieve at least this level of performance. Figure 1 shows the main sources of energy losses and areas for improving the efficiency of steam boilers.

Figure 1 Improving the energy efficiency of shell boilers



Target shell boiler efficiency

A recent UK survey of 300 boilers over 100 sites indicated a boiler efficiency range of 51-82%, with an average of 74.2%. Most sites should be able to achieve a target boiler efficiency of 80% (based on the gross calorific value of the fuel).

Measures of efficiency

The percentage of the fuel input energy that is eventually delivered as useful heat output is a measure of the efficiency with which the boiler is operating. Not all the heat released when the fuel is combusted can be used. Some heat is never released due to incomplete combustion. Some heat is lost as hot flue gases leave the boiler and some heat is lost from the boiler to its surrounds.

Many measures of performance can be used to define efficiency. Two common measures are combustion efficiency and boiler efficiency.

- **Combustion efficiency** is defined as the percentage of energy in the fuel that is released after combustion within the boiler. Some of the energy contained in the fuel is lost due to incomplete combustion.

$$\text{Combustion efficiency (\%)} = \frac{\text{Actual energy released during combustion}}{\text{Total energy content of the fuel}} \times 100$$

or

$$\text{Combustion efficiency (\%)} = 100 - \text{percentage heat lost due to incomplete combustion of fuel}$$

Combustion efficiency for gas and liquid fuels is usually quite high (around 99%).

- **Boiler efficiency** is defined as the proportion of useful heat output compared with the heat input. It takes account of heat losses to the flue gases, heat losses due to incomplete combustion of the fuel, radiation losses (from the exposed boiler surfaces, etc.), convection losses, conduction losses and other ancillary losses.

$$\text{Boiler efficiency (\%)} = 100 - [\text{Flue gas losses} + \text{Radiation and other losses (unaccounted)}]$$

Flue gas losses, which are dependent on the excess air, are the major contributor to a reduction in boiler efficiency.

The efficiency of a boiler is quoted as the percentage of useful heat available expressed as a percentage of the total energy potentially available by burning the fuel. This may be expressed as either gross efficiency or net efficiency, depending on whether the gross or the net calorific value of the fuel is used when calculating the energy content of the fuel. A realistic target is an overall boiler efficiency of 80% (based on the gross calorific value of the fuel).

Tax breaks when buying listed energy efficient equipment

The Energy Technology List is designed for companies and organisations wishing to procure energy efficient equipment and details over 6,200 products that meet Government-prescribed energy efficiency criteria. A key feature of the Energy Technology List is that it provides details of specific equipment and suppliers.

Investment in products listed on the Energy Technology List may also qualify for an Enhanced Capital Allowance (ECA), a tax relief permitting businesses to deduct 100% of capital expenditure against their taxable profits in the first year. Qualifying expenditure can include the cost of buying the equipment as well as the cost of installation and transporting the equipment to the site.

Businesses may pay less tax on their profits when investing in energy-saving boiler plant equipment falling within the following types, as listed on the Energy Technology List (others may be added later):

- Advanced boiler controls and additional energy saving add-ons
- Automatic TDS control of feedwater in boiler
- Biomass boilers (>300kW and <15,000kW)
- Blowdown systems
- Boilers over 400kW thermal output
- Burners and controls
- Condensate return systems
- Condensing boilers up to 400kW thermal output
- Condensing economisers
- Flue gas economisers
- Heat recovery from boiler blowdown
- Oxygen trim controls
- Pipe insulation
- Sequence controls
- Variable speed drives.

For the latest information about the Energy Technology List and ECAs, visit www.eca.gov.uk or call the Action Energy helpline on 0800 58 57 94.

How to use this guide

The following sections of the guide deal with the principal issues concerning the efficient operation of steam boiler systems. Each section offers a brief explanation of the appropriate technology and a description of key operational issues, maintenance requirements and energy savings potential. An example calculation of the energy and carbon savings obtained from a 1% increase in boiler efficiency is given in the Appendix.

The guide also contains a glossary and a list of publications offering further information on the energy efficient operation of steam boiler plant.

- ***Readers new to steam boilers** are encouraged to read the guide in its entirety to gain an understanding of the key efficiency issues, operational issues, maintenance implications and potential energy savings.*

- ***Experienced boiler operators** who are seeking a reminder of energy efficiency issues should refer to the summaries of key operational considerations and energy savings potential. This will help with reviewing and maintaining effective maintenance procedures and plant operations.*

2 Boiler operation and maintenance

Most equipment operates best when it is new and recently commissioned. Effective maintenance is necessary to sustain optimum performance and to prevent faults or inefficient operation.

Any facility where steam is generated, distributed and used should strive for high maintenance standards and adopt good operational procedures and practices. Sophisticated engineering and control systems are increasingly replacing manual control by plant operators.

This section examines:

- *Boiler losses*
- *Conversion of fuel to heat*
- *Pollutant releases*
- *Cleanliness of heat transfer surfaces*
- *Radiation losses*
- *Plant scheduling*
- *Water level control systems*
- *Record-keeping*
- *Operational best practice.*

Boiler losses

It is generally more useful in terms of energy efficiency to determine the overall boilerhouse performance by taking into account all the relevant factors (combustion efficiency, boiler blowdown, standby boilers, low load operation and other losses).

The main losses in efficiency are due to a combination of the following:

- Not all the energy stored in the fuel can be usefully recovered. Unburned or partially combusted solid, liquid or gaseous fuel may be ejected from the boiler.
- Most fuels contain hydrogen and this combines with oxygen to produce water vapour. The latent heat contained in this vapour is usually lost as it exhausts from the boiler flue (except in condensing boilers).
- Too much combustion air increases flue gases losses.
- The boiler shell is hot and significant quantities of heat are radiated from the boiler to its surroundings.
- Heat is lost in the boiler blowdown necessary to maintain an acceptable TDS content.

All these losses must be taken into account when considering boiler efficiency and the potential for energy and cost savings. A steam energy efficiency cost calculator is given in **ECG066 Steam generation costs**.

Factors affecting boiler efficiency

- *Efficiency increases when load requirements are steady, consistent and continuous*
- *Efficiency is reduced with periods of no load or low load, boilers banked or on hot standby, and short-term load swings*
- *Savings of up to 5% of fuel input are possible through improvements to the operating regime.*

Conversion of fuel to heat

Unlike steam leaks, fuel wastage due to an incorrect fuel to air ratio is not readily apparent. Regular or continuous monitoring of flue gas conditions is therefore necessary to identify such problems.

Burners are fitted with safety mechanisms to control light-up sequence (pre and post purge), flame failure detection systems, etc. Integrated control packages are available that provide boiler and combustion management, and incorporate many or all of these individual safety features. These controls usually incorporate a diagnostic system.

Sequence controllers can also save energy by minimising the energy losses associated with rapid cycling (from pre and post purge ventilation losses).

Excess air control, boiler and burner management systems are considered in section 6.

Emissions

A close relationship generally exists between energy efficiency and waste emissions. Energy efficiency and waste minimisation objectives are therefore complementary as efficient operation ensures that pollution levels are minimal.

Carbon dioxide (CO_2) is one of the products of combustion and has been identified as one of the six main gases of concern with respect to global warming. CO_2 emissions can be minimised by ensuring optimum combustion efficiency. Typical CO_2 emissions from common fuels are given in Table 2. Other pollutants from combustion can include particulates, sulphur oxides (SO_x) and nitrogen oxides (NO_x).

***Table 2** Carbon dioxide emissions from common fuels **

Type	Units	kg CO_2 per unit
Grid electricity	kWh	0.43
Natural gas	kWh	0.19
	Therms	5.50
Gas/diesel oil	kWh	0.25
	Litres	2.68
Heavy fuel oil	kWh	0.26
	Tonnes	3,117
Coal	kWh	0.30
	Tonnes	2,419

* Data from Defra publication 'Environmental Reporting Guidelines for company reporting on greenhouse gas emissions', available on Defra web site (www.defra.gov.uk).

Fouling

Fouling of the heat transfer surfaces of a boiler can occur on either the gas or water side of the tubes. The gas side can become fouled with soot or other products of combustion. Both types of fouling reduce the amount of heat transferred from the flue gases to the boiler water. This increases flue gas temperatures and hence reduces boiler efficiency. Poor control of water treatment, poor control of combustion, operation at low load or frequent stop/starts will necessitate more frequent cleaning.

Section 3 considers water side fouling in more detail and examines the impact of increased temperatures on the need for cleaning.

Key issues - heat transfer surfaces

- *A 20°C increase in the flue gas temperature over the normal operating temperature will reduce efficiency by around 1% of fuel heat input*
- *Clean the gas or water side if the flue gas temperature increases by 20-40°C compared with the clean boiler condition.*

Radiation losses

These losses refer to the heat losses from the surface of the boiler and are a combination of convection and radiation heat transfer.

The radiation loss from modern boilers should be only around 1% of the heat input rating, but it may be considerably higher on older boilers and could be as high as 10% of fuel input on plant with poor or damaged insulation.

The radiation loss is fixed while the boiler is firing and therefore represents a higher overall proportion of losses if firing is sustained at low load levels.

Radiation losses can be assessed by monitoring the boiler's fuel consumption under hot standby conditions.

Key issues - radiation losses

- *Maintain boiler insulation in good condition*
- *Insulate all pipework, valves, flanges and fittings in the boilerhouse and replace valve mats/covers after maintenance work.*

Scheduling and sequence control

Boiler efficiency changes with firing rate. Therefore, the way in which several boilers are operated to meet a variable load can have a significant bearing on overall efficiencies. Load scheduling and boiler sequencing systems are discussed in more detail in section 6.

Where it is necessary to use more than one boiler to meet a variable load, it is useful to determine the efficiencies that can be achieved with different combinations of boiler and different combinations of firing rate, and then use the one giving the highest efficiency.

Water level control systems

Water level controls and level gauge glasses are essential safety features and can be mounted either externally or internally. They are blown down daily during routine testing.

Level control systems should be routed to the blowdown vessel (see section 5) and not to the blowdown flash vessel or the heat recovery system.

Record-keeping

Regular analysis of records of boiler and water treatment parameters can help to determine whether the boiler is operating properly or showing any signs of problems that require attention.

Such records are normally kept in the form of daily logbooks. Examples of suitable logbooks are given in Figure 2 and in:

- Health and Safety Executive (HSE) Plant and Machinery Guidance Note PM5 Automatically controlled steam and hot water boilers
- BS2486:1997 Recommendation for treatment of water for steam boilers and water heaters.

In addition, a water treatment specialist should undertake independent monthly tests and inspect trends in the daily water treatment logs.

Figure 2 Example daily log sheet for steam boilers

Date:								Plant:											
		Steam		Water				Flue gases			Draught		Fuel					Air	
Time	Boiler no.	Pressure (bar)	Temp. (°C)	Temp. econ. inlet (°C)	Temp. boiler inlet (°C)	Meter reading feedwater (litres)	Meter reading make-up water (litres)	Temp. boiler outlet (°C)	Temp. econ. outlet (°C)	CO_2 or O_2 (%)	Pressure in combustion chamber (bar)	Pressure at boiler outlet (bar)	Flow meter (kg.m³ or litres)	Return meter (kg.m³ or litres)	Flow temp. (°C)	Return temp. (°C)	Ashes (kg)	Outside temp. (°C)	Comments
Total																			
No. of readings																			
Average																			

Daily summary

Fuel type and grade ....

Fuel used (metered) ....

Fuel used..kg

Evaporation of steam: total ....kg

Ashes: total ....kg

Density (20/20)...

or calorific value ....kJ/kg or kJ/m³

Fuel used (corrected to 20ºC) ....

Evaporation of steam per kg of fuel...........................kg

= ....% of fuel

Feedwater
Meter reading (start of day) ....litres
Meter reading (end of day) ....litres
Difference ....litres
Make-up water...litres = ...% of evaporation

Blowdown (total) time... Quantity ....

Operators on duty	Shift 1	Shift 2	Shift 3	Comments

Operational best practice

Operational regimes can have a significant impact on boiler efficiency.

Key issues include:

- Reducing standing losses, by installing flue gas or forced draught fan isolation dampers (see section 8) and by minimising the number of boilers kept on hot standby
- Reducing short-term load swings, by installing steam accumulators or by demand side management (e.g. improved production scheduling)
- Avoiding operating boilers at low load, by reducing the number of boilers in operation (see section 6) or by using alternative means to serve local heat loads.

Key operational considerations – boiler operation and maintenance

- *Maintenance has a direct impact on energy consumption*
- *Improved fuel to air ratios improve efficiency and can be achieved through better controls and regular burner servicing*
- *Clean heat transfer surfaces (gas side and water side) will reduce flue gas losses and improve efficiency*
- *Scheduling the boilers to match the load improves efficiency.*

3 Water treatment

This section contains advice on how to optimise energy efficiency through the application of good water treatment.It explains the need for water treatment and conditioning regimes and focuses on those aspects that affect the efficient operation of steam boiler plant (notwithstanding the overriding requirement for safety and reliability).

The issues addressed in this section include:

- *Reasons for water treatment*
- *Types of water treatment*
- *Scale and water side fouling*
- *Corrosion*
- *TDS control and blowdown*
- *Carryover*
- *Chemical cleaning and boiler storage regimes.*

Why treat water?

Water is an excellent solvent in which many compounds readily dissolve. It is also an excellent medium for transporting suspended and colloidal material. However, the presence of these impurities and contaminants makes appropriate water treatment and conditioning regimes essential, to provide water of a suitable quality for the effective operation of steam boiler plant and systems.

Various parameters can be measured and used to describe water quality. The commonest are hardness, alkalinity, TDS, suspended solids, pH and dissolved gases (principally oxygen and carbon dioxide).

The main areas of concern with poor water quality, which are often interrelated, are:

- Scale
- Deposition
- Corrosion
- Biological activity (not generally applicable to packaged shell boiler systems and not considered in this guide).

The water used in steam boilers can be supplied from many different sources and will contain various contaminants and impurities. If water is used directly in steam boilers without treatment, then these contaminants and impurities can cause water side fouling and corrosion, and, ultimately, plant failure. Hard water contains mainly calcium and magnesium salts and, when heated, results in scale formation (see below). Soft water is preferable for use in boiler plants because it is easier to make slightly alkaline, helping to prevent corrosion.

Poor water treatment and boiler water conditioning can:

- Reduce the steam generating efficiency of boiler plant through fouling of water side heat transfer surfaces and increased blowdown
- Increase the cost of routine boiler cleaning operations (chemical and mechanical) and the need to repair/replace corroded parts
- Result in carryover and reduced heat delivered to components using the steam system
- Result in catastrophic plant failure if sustained over a significant period
- In addition, insurance, warranties, guarantees or leasing terms may require the demonstration of appropriate water treatment.

According to BS2486:1997 (Recommendation for treatment of water for steam boilers and water heaters), the complementary objectives of water treatment are to:

- Contribute to the overall safety of operation of the boiler
- Assist in the maintenance of high heat transfer efficiency by preventing scale and corrosion
- Maintain the quality of the generated steam.

This section deals primarily with the second objective.

Types of water treatment

Modern boilers tend to be compact and have a high rating, so they may require closer control of water side parameters than older or moderately rated plant, which can tolerate more extreme water conditions.

Treatment is generally divided into two forms:

- External treatment – applied before the water enters the boiler to remove or modify problem mineral salts
- Internal treatment (sometimes referred to as boiler water conditioning) – chemicals are added directly to the feed or boiler water to prevent scale formation and corrosion.

For more information about the different types of water treatment, see **GPG221 Improving boiler energy efficiency through water treatment**.

Scale

Scale forms in boilers when various dissolved constituents in boiler feedwater come out of solution and deposit on the heating surfaces due to changes in temperature, density and concentration as the water evaporates in the boiler.

The dissolved constituents that cause the most problems in boiler systems are calcium and magnesium salts. As the water is heated, these salts become less soluble and precipitate out. Part of the purpose of water treatment is to prevent this from happening, or to ensure that the precipitate does not adhere to the metal surfaces and can be safely removed by blowing down the boiler.

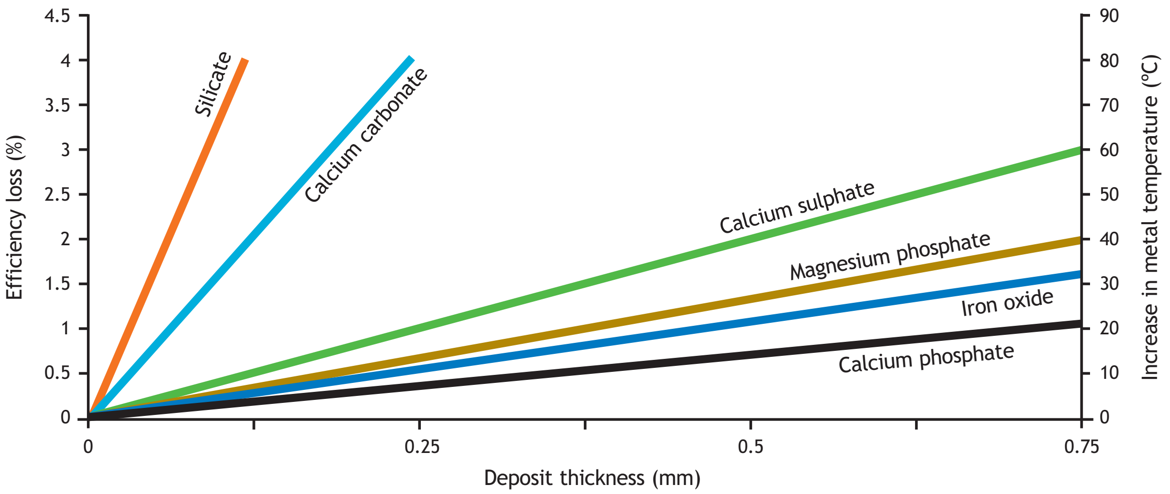
The type of water side fouling depends upon the chemical constituents of the water, as well as the water treatment and conditioning regime. The impact on boiler efficiency of common scale-forming compounds is illustrated in Figure 3, which shows that even very thin layers of these compounds can be significant.

These scales also increase metal wall temperatures and, in extreme cases, can reduce the metal's tensile strength, resulting in overstressing and failure of the metal. Silicon-based deposits are particularly problematic, but detailed consideration of this topic is outside the scope of this guide.

Key issues - scaling

- *A 20ºC rise in flue gas temperature due to reduced heat transfer arising from water side scaling and/or fireside fouling reduces efficiency by 1% of fuel input*
- *Ensure that any precipitated salts do not adhere to heat transfer surfaces by proper feedwater treatment and regular cleaning of the water side of boiler tubes*
- *Ensure that any precipitated salts are removed easily by blowing down the boiler as recommended by the boiler manufacturer.*

***Figure 3** The effect of scale on boiler efficiency*



Corrosion

Most boilers are constructed from various grades of steel. Some metal oxides form stable coatings that adhere to the base metal and protect it from further attack. Other metal oxides are porous, unstable and easily broken down; these do not provide protection. The aim of boiler water conditioning is to promote conditions within a boiler that encourage the formation of the protective and stable iron oxide, magnetite, rather than the porous and unstable iron oxide, haematite.

Magnetite can form haematite in the presence of oxygen in the boiler water; acidic conditions provide the electrolyte required for the corrosion mechanism. Corrosion eats away the metal, reducing its overall strength and leading to eventual failure. The aim of water treatment and conditioning regimes is to control dissolved oxygen and pH levels to within the levels recommended by the boiler manufacturer or a relevant standard (e.g. BS2486:1997 or an American Boiler Manufacturers Association (ABMA) or European equivalent. Such a programme should be developed with the support of a water treatment specialist.

Numerous corrosion mechanisms can occur in boiler and feed systems, but further discussion of this topic is outside the scope of this guide.

Control of water treatment and conditioning

Early detection of contamination or deviation from agreed parameters is essential. An application and control strategy, which satisfies safety and reliability requirements, should be co-ordinated with a water treatment specialist.

A schedule of routine sampling, monitoring and test procedures to test representative samples of water should be agreed with a water treatment specialist and the results used to adjust the treatment regime to maintain boiler and feedwater parameters within certain recommended limits. Short excursions are acceptable, but sustained excursions should be avoided as they will lead to scale formation and corrosion. Typical limits are given by boiler manufacturers, and general guidelines are provided in BS2486:1997 Recommendation for treatment of water for steam boilers and water heaters.

Water treatment is expensive: aim to use the minimum necessary.

Key issues – corrosion

- *Corrosion causes leakage and reduces plant life*
- *Protect the metal surfaces of the boiler from attack by acid or strong alkalis*
- *Control pH levels in the boiler to give an alkaline environment in a safe range (pH 8.2-12.5)*
- *Limit the oxygen concentration in boiler water by mechanical de-aeration (e.g. using cold de-aeration, pressure de-aerators or feed tank heaters) and by using chemical oxygen scavengers to deal with any residual oxygen*
- *Consider adding neutralising or filming amines to control corrosion in condensate systems.*

Key issues – water treatment control

- *Undertreatment = corrosion and fouling, waste of energy*
- *Overtreatment = extra cost and fouling, waste of energy*
- *Water treatment chemicals add to TDS levels. Excess levels will result in increased blowdown and loss of energy.*

Carryover

Water entrained in the steam leaving the boiler is called carryover and contains TDS from the boiler water and water treatment chemicals.

Carryover can be caused by chemical or mechanical means. It should be avoided or reduced to a practical minimum as it can cause deposition in the plant and steam distribution system, thereby reducing performance and efficiency. Foaming due to high levels of TDS and alkalinity in the boiler water can also cause operational problems, such as salt deposits and pipework corrosion.

Carryover can be limited by correct plant control by operators.

- Operators can influence the chemical causes of carryover by:
  - Controlling suspended solids levels
  - Avoiding high alkalinity levels
  - Avoiding the introduction of oils and soap-like substances.
- Operators can influence the mechanical causes of carryover by:
  - Avoiding operation at lower than design pressure
  - Avoiding operation at high water levels to minimise risk of priming
  - Ensuring internal steam baffles or external steam separators operate properly
  - Matching the burner firing rate to the load
  - Controlling the feed water by means of a modulating control valve rather than an on-off feed pump. For rapid load changes a two element level control system based on measuring the steam flowrate can be considered.

Key issues – carryover

- *Carryover can cause potentially dangerous water hammer, corrosion, reduced heat transfer and damage to the steam distribution system*
- *Train operators to take action to minimise the chemical and mechanical causes of carryover.*

Key issues – chemical cleaning

- *Chemical cleaning is required to keep heat transfer surfaces clean and to maintain efficiency*
- *Be aware of indications of the need for cleaning and implement appropriate procedures if these are observed.*

Boiler cleaning and storage

Severe corrosion can occur if a boiler is shut down and left partly filled with water for a significant period. Proper storage procedures should therefore be followed. Procedures for wet storage (fully flooded), maintaining normal water level and dry storage (ventilated) are recommended by boiler manufacturers and in BS2486:1997 Recommendation for treatment of water for steam boilers and water heaters.

New boilers and plant subject to a major repair or overhaul generally receive a pre-commissioning clean and possibly a steam blow.

Deposits will build up during the life of a boiler and, if these deposits cannot be removed by mechanical means, it is necessary to carry out chemical cleaning of the internal boiler surfaces. Chemical cleaning is technically demanding and specialist advice should always be sought. The frequency of boiler cleaning will depend on a number of operational factors, including the effectiveness of the water treatment regime.

Indications of the need for cleaning include:

- Observation of scale or other deposits
- An increase in specific energy consumption (i.e. kWh/kg steam produced)
- An increase in the time needed to reach operating temperature and pressure from the same start up condition
- A known occurrence of contamination
- A rise in flue gas temperature compared with the clean condition.

Energy saving potential of correct water treatment

The impact of any scale deposits is determined by the composition and thickness of the scale. Scale will lead to a rise in the flue gas temperature. As a rule of thumb, for each 20ºC rise in flue gas temperature, the efficiency will fall by 1% of fuel input.

Improved control of water treatment saves money and energy

A tyre manufacturer installed automatic blowdown and feedwater controls, and reduced its annual blowdown requirements, which resulted in energy savings worth £12,000/year and chemical cost savings worth £4,750/year. Effluent charges also fell. Total annual savings of £22,000 were achieved for an investment of £17,120, giving a payback period of nine months. For more information, see **GPCS383 Energy savings through effective control of boiler water treatment**.

Energy saving potential: water treatment and boiler water conditioning

- *Careful control of boiler water chemistry saves energy*
- *Reducing feedwater TDS reduces blowdown and saves energy*
- *Maximising condensate return saves energy and reduces the cost of water treatment*
- *Good chemical control saves money and protects expensive assets.*

4 TDS control and boiler blowdown

The total quantity of mineral salts that can be tolerated in a boiler depends on the boiler design. When water is evaporated and steam generated in a boiler, the concentration of both the dissolved and suspended solids in the remaining boiler water increases. Controlling the quantity of total dissolved solids (TDS) is an integral part of boiler water treatment (see section 3).

This section addresses the following key issues for energy efficient operation of boilers:

- *Recommended TDS levels*
- *Blowdown*
- *Condensate return.*

Recommended TDS levels

Typical figures are given in Table 3 below.

Type	Maximum TDS (ppm)
Smoke and water tube up to 10bar	5,000
High pressure water tube	3,000-3,500
Packaged and economic	3,000

* These figures are recommended as a guideline, but the boiler manufacturer's recommendations may differ and should be followed at all times.

What is blowdown?

To maintain the TDS concentration below the maximum recommended level, water at the steam temperature must be blown down from the boiler and replaced with cooler make-up water with a lower TDS content. This process removes some of the suspended and dissolved solids in the boiler water.

Typically between 1% and 5% of the energy input to the boiler is lost in blowdown. Before discharge to drain, it is also necessary to cool blowdown water to below 43ºC (to comply with consent conditions and thus avoid detrimental effects at sewage treatment works). This is achieved by diluting it in the blowdown vessel with cold water. If the make-up water is treated, the blowdown process also has associated chemical costs.

The correct level of TDS required for a particular boiler is controlled either manually or automatically. The blowdown regime can be intermittent or continuous, or a combination of both.

In manual systems, a representative sample of the boiler water is tested; the correct TDS level is maintained by the operator controlling how often and how long the manual boiler bottom blowdown valve is opened. This form of control is basic and can result in wide fluctuations in measured levels of TDS. Provided the boiler can withstand these variations, this is generally not a problem as long as the severity and duration of the variations are within limits accepted by the boilermaker and approved by the water treatment specialist.

With manual control, lower TDS levels are usually maintained, because much higher margins of error have to be allowed for. Blowdown and energy loss therefore tend to be higher than necessary. Operation at TDS levels significantly below the recommended levels wastes fuel, due to the excessive amounts of boiler water being discharged to drain.

It is therefore preferable to provide automatic control of TDS levels. Automatic control devices rely upon sensors, and monitoring and control equipment to regulate blowdown via an automatically controlled boiler blowdown valve. This valve is usually provided in addition to a manual bottom blowdown valve, which is often still used to give bottom blowdown or to test water level controls. For more information, see **GPG221 Improving boiler efficiency through water treatment.**

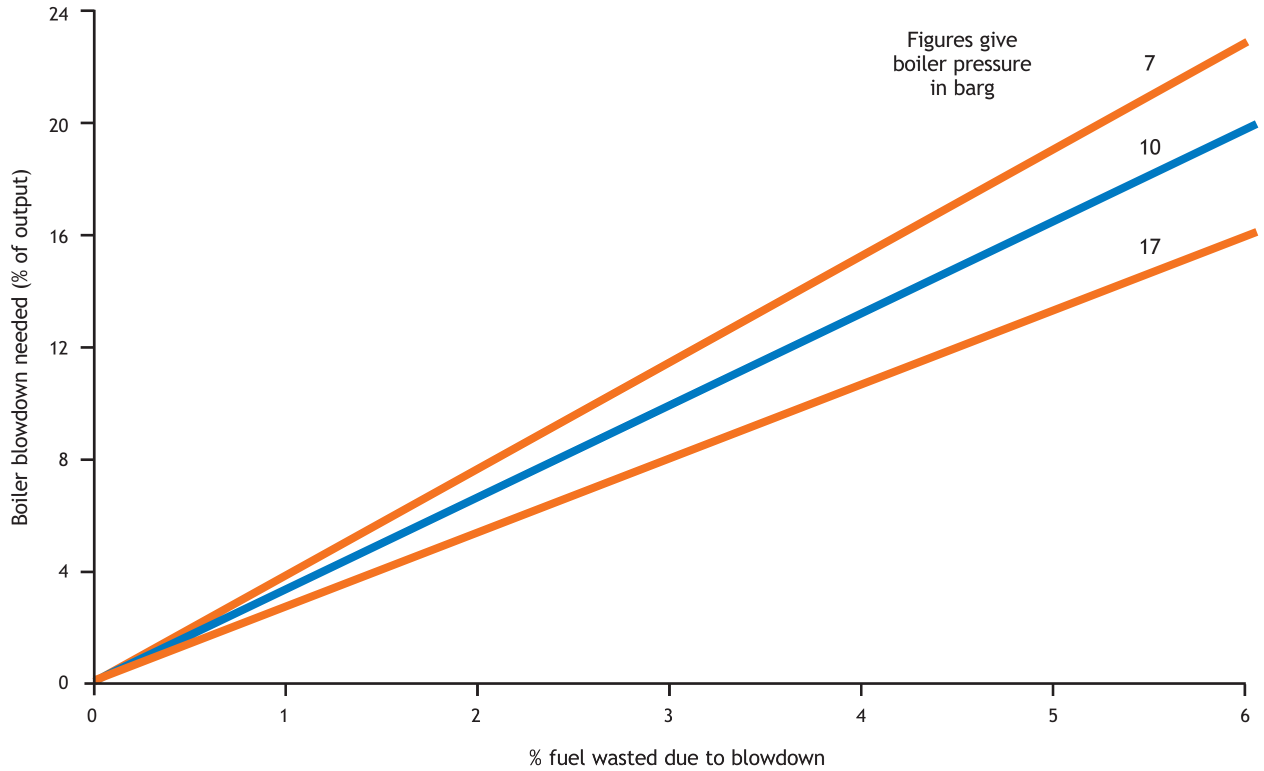
Automatic TDS control systems should be inspected, cleaned and calibrated regularly (particularly the probe as it operates in arduous service conditions).

Figure 4 indicates the extent of the energy losses associated with blowdown, while the fuel savings from reduced blowdown are given in Table 4.

Table 4 *Fuel savings from reduced blowdown*

Boiler pressure (barg)	Percentage fuel saved for 1% reduction in blowdown
7	0.19
10	0.21
17	0.25
25	0.28

Figure 4 *Energy losses associated with blowdown*



Energy saving potential: automatic TDS control

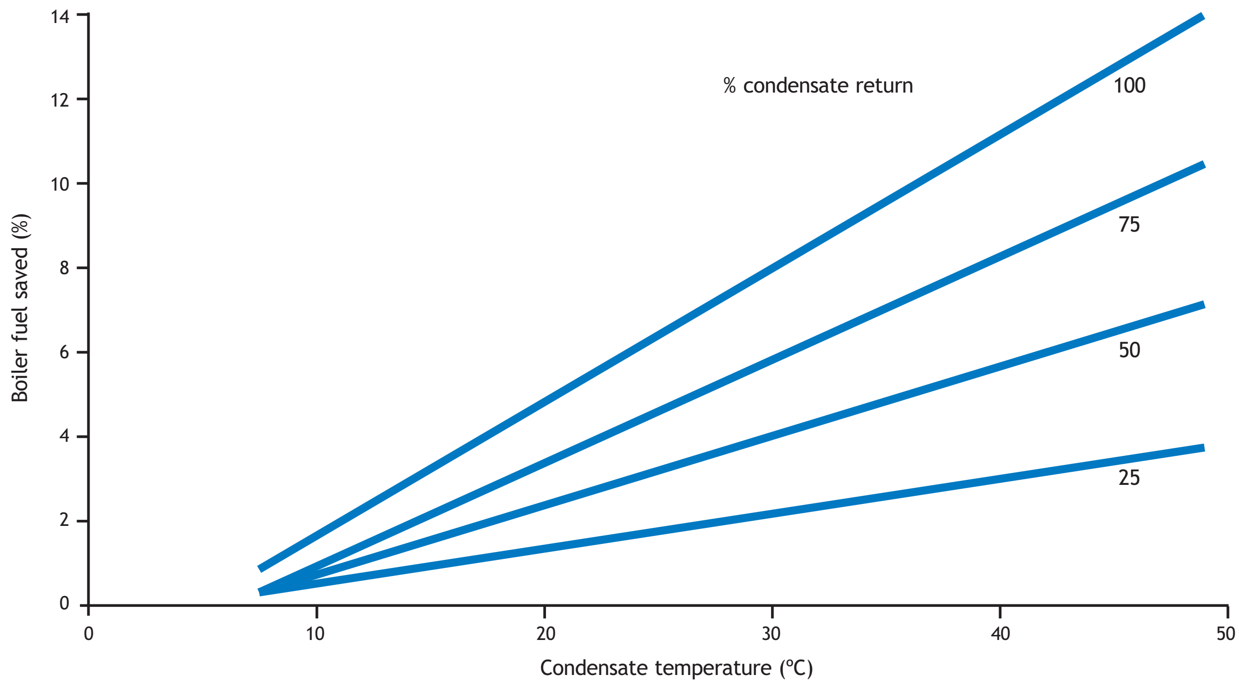
- *Possible savings of up to 2% of fuel input*
- *New equipment may qualify for an Enhanced Capital Allowance (see section 1 and www.eca.gov.uk).*

Condensate return

Condensate carries with it a significant proportion (around 20%) of the original heat input from the fuel. Maximising the amount of condensate returned therefore leads to economies in respect of boiler blowdown (saving energy) and in water treatment costs (less pretreatment and conditioning is needed, because the condensate has been treated and has low TDS level). Figure 5 shows the savings obtained for different percentages of condensate (return) and condensate temperature.

In situations where feedwater contamination can occur, the quality of the condensate can be monitored (e.g. by measuring conductivity or for the presence of oil) and, if contamination is detected, the condensate can be discharged to drain automatically.

***Figure 5** Fuel saved by condensate returned*



Key operational considerations: TDS control and boiler blowdown

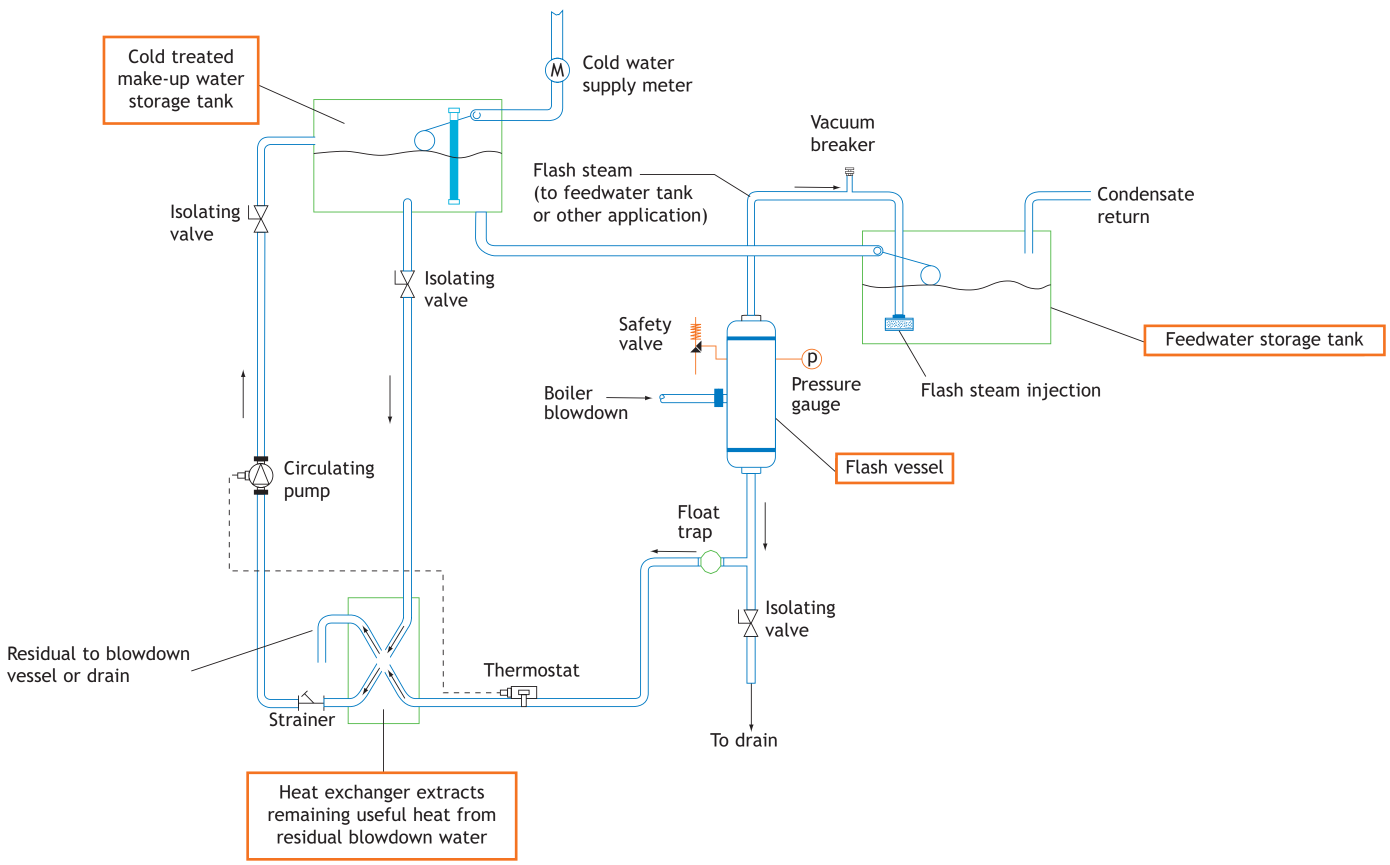
- *Use the minimum quantity of blowdown necessary*
- *Close control of TDS limits boiler blowdown to a practical minimum and saves energy*
- *Improve energy and water treatment efficiency by maximising the amount of condensate returned.*

5 Heat recovery from boiler blowdown

Both energy and water treatment efficiency can be improved by recovering flash steam and residual heat from blowdown. Boiler blowdown water has to be cooled in a blowdown vessel or tank to below 43ºC before it can be discharged to an effluent treatment system or to drain. Up to 80% of the heat in the boiler blowdown water can be recovered.

Heat recovery can be affected using flash steam recovery vessels, heat exchangers or both. Such measures save energy by increasing the temperature of the feedwater to the boiler and reducing the amount of fuel consumed in the boiler. Figure 6 shows a typical system with recovery of both flash steam and residual heat from blowdown water.

Figure 6 Typical blowdown heat recovery system



Energy saving potential blowdown heat recovery

- *Blowdown heat recovery can reduce blowdown energy losses by up to 50%, to give an energy saving of 0.5-2.5% of heat input in a boiler plant. Heat recovery from the remaining blowdown watercan provide further savings of up to 25%, providing a total energy saving of 0.75-3.75% of heat input.*
- *New equipment may qualify for an enhanced capital allowance (see section 1 and www.eca.gov.uk).*
- *Use calculation charts provided by manufacturers to help with equipment selection and to evaluate energy savings.*

Recovery of flash steam

Passing the blowdown water through a flash vessel generates low-pressure steam. The flash steam that separates as the pressure is reduced after the boiler blowdown valve can then be collected.

Flash steam can be used for feed tank heating or other uses. This system of heat recovery is suitable for plants with continuous blowdown systems.

Heat recovery from boiler blowdown

Further heat can be recovered from the remaining blowdown water via a heat exchanger. The recovered heat can be used, as appropriate, to preheat boiler make up water, for process heating or hot water applications.

Heat recovery systems are not usually suitable for bottom blowdown systems with intermittent and peaky flow rates.

Heat recovery gives energy and cost savings

At a Devon creamery, a steam recovery vessel is used in conjunction with an automatic TDS system to minimise blowdown and to recover heat from the flash steam. Energy savings worth £5,740/year have been achieved for an investment cost of £9,660, giving a payback period of 1.7 years.

For more information, see **GPCS339 Heat recovery from boiler blowdown.**

6 Boiler and burner management systems

Proper control of combustion conditions is essential both to increase boiler efficiency and to minimise pollutant releases (see section 2). This section addresses the following key issues:

- *Optimisation of boiler combustion conditions*
- *Combustion and management control systems*
- *Boiler sequencing control systems*
- *Oxygen trim controls.*

Optimisation of boiler combustion conditions

Detailed information on how to optimise the performance of burner systems is given in **GPG252 Burners and their controls**.

Combustion and excess air

When the fuel is burnt in the boiler furnace, some of the chemical energy contained in the fuel is released as oxidation takes place. The process of combustion requires good fuel/air mixing and the correct quantity of air.

In almost all cases, it is practically impossible to achieve full combustion with the theoretically required (stoichiometric) volume of air. In practice, more air is usually required, i.e. excess air. Close control of the amount of excess air is essential both to ensure full combustion and to prevent excessive cooling, because the excess air absorbs heat and reduces heat transfer to the boiler water. Excess air is typically 15-25% (more for coal), but the exact amount depends on the fuel, burner make and type, firing rate, etc.

If too little combustion air is supplied, it is impossible for all the fuel to burn completely. Incomplete combustion is expensive and even small variations in the amount of combustion air can have significant cost implications. Contrariwise, incomplete combustion can occur even when excess air is supplied; complete combustion relies on many factors including mixing and flame shape.

Assessing efficiency

BS845:1987 (Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids) describes the methods and conditions under which a boiler should be tested to determine its efficiency. To enable its efficiency to be calculated, a boiler needs to be operated under steady load conditions (generally full load) for an hour before readings are taken during the next hour of steady operation. In practice, it is often useful to determine the average efficiency of operation achieved over a varying load pattern.

If operated correctly, most modern boilers have similar operating efficiencies. Table 5 shows the expected boiler efficiencies that may be obtained for different boiler types (based on the gross calorific value of the fuel).

***Table 5** Typical boiler efficiencies*

Type	Efficiency (%)*
Condensing gas	88-92
High efficiency modular	80-82
Shell boiler (hot water)	78-82
Shell boiler (steam)	78-82
Reverse flame	74-80
Cast iron sectional	70-76
Steam generator	75-78
Water tube with economiser	78-84

* Gross calorific value basis

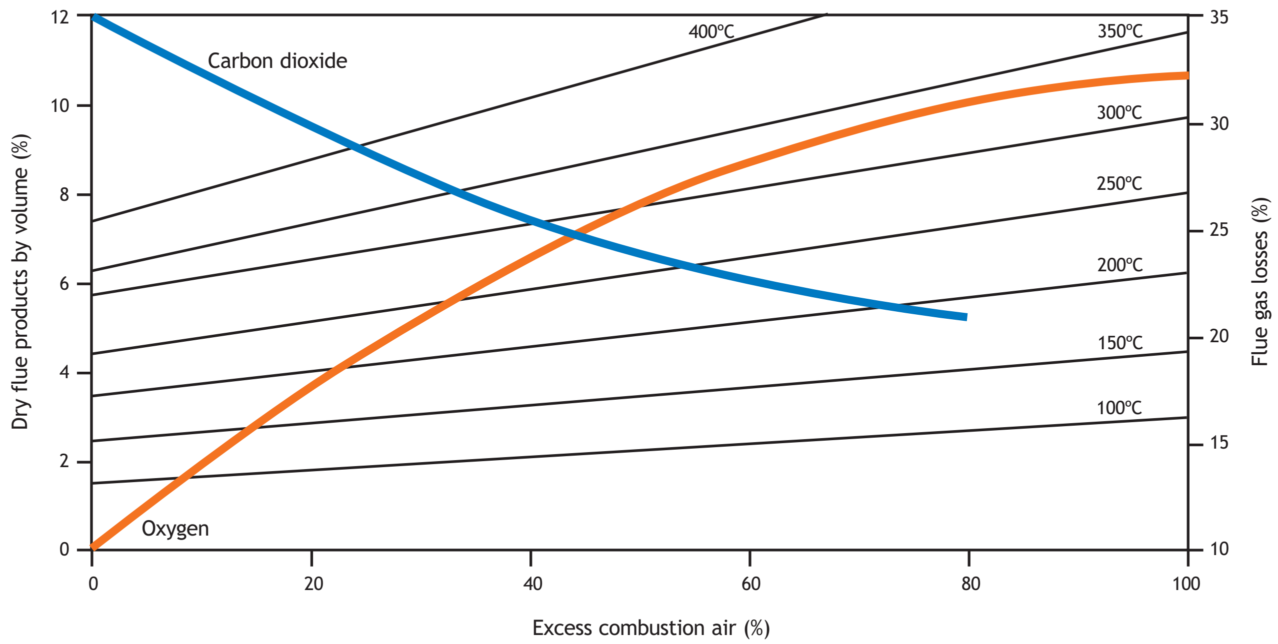
BS845:1987 does not describe how to determine the overall boilerhouse performance, as this depends on a range of operational and design parameters such as standby losses, blowdown losses, low load operation, feed heating requirements, etc. Comprehensive metering of steam supply, condensate returned, make-up water and fuel consumption will, however, provide a reliable indication of overall boiler plant efficiency.

The losses associated with incomplete combustion and incorrect air supply can be determined by examining the oxygen and carbon dioxide content of the flue gases and the temperature of the flue gas. An analysis of the relationship between these three parameters allows combustion efficiency to be determined and combustion airflow to be corrected.

A typical example of this relationship for natural gas firing is shown in Figure 7 (similar charts are available for other fuel types). Provided the carbon dioxide (or oxygen) level in flue gas and its temperature are known, the heat loss to the flue gas can be estimated from Figure 7 as follows:

- Locate the appropriate point on the carbon dioxide or oxygen curve
- Move vertically up or down to the correct line for flue gas temperature
- Read off the corresponding percentage flue gas loss from the right-hand y-axis.

Figure 7 *Effects of excess air and flue gas temperature on heat loss to flue gas (for natural gas)*



Differing amounts of excess air are usually required to complete combustion at different firing rates. Fuel/air velocities may be reduced at lower firing rates and good mixing can only be achieved by increasing the amount of excess air supplied. Traditionally, this has been achieved by controlling airflow to the burners with a damper and an adjustable snail cam. Illustrations of the effect of a reduction and an increase in excess air, possible savings or losses due to changes in boiler efficiency and the effect of higher flue gas temperatures are provided in the Appendix at the end of this guide.

Combustion quality can be monitored automatically and, with the advent of electronic variable speed drive technology, it is possible to monitor and adjust combustion airflow continuously over the entire firing range to ensure maximum efficiency.

For energy efficient operation it is vital that these fundamental, but relatively simple issues are given priority.

Combustion and management control systems

The amount of fuel used in a burner is critically dependent upon the control of the air to fuel ratio. Modern digital control systems offer precise adjustment and optimisation of air and fuel characteristics.

Energy savings of up to 5% can be obtained by implementing digital combustion and boiler modulation controls. These reduce fuel consumption and improve turndown ratios. They can be used in combination with other stand-alone technologies such as oxygen trim control and variable speed forced draught fan control.

Proprietary systems offered by specialist manufacturers are known by terms such as digital combustion and management control (DCMC), direct digital combustion control (DDCC), micro modulation and intelligent boiler sequencing.

Note: Where combustion analysers and/or oxygen trim controls are not fitted, a detailed assessment should be carried out to see if retrofitting the instrumentation to existing boiler plant is justified in terms of potential savings. It may be worth considering the use of portable combustion analysers that measure oxygen or carbon dioxide and carbon monoxide.

Key issues – optimisation of boiler combustion controls

- *Check combustion conditions (flue gas temperatures, flue gas constituents, flame shape, fuel and air trim settings) regularly as a matter of routine*
- *Minimise flue gas oxygen levels without producing smoke or excessive levels of unburnt carbon*
- *A two percentage point reduction in oxygen levels in the flue gas will give a fuel saving of 1.2%.*

Key issues – sequencing controls

- *Review the number of boilers needed to meet requirements and, if possible, reduce the number in service*
- *Eliminate, where possible, the use of boilers on hot standby at full pressure*
- *Set boiler sequencing controls (when installed in a multi-boiler plant) to adjust the number of boilers and firing rate to suit the load pattern.*

Boiler sequencing control systems

When more than one boiler is available, sequencing control systems save energy by matching the number of boilers and their firing rates to meet and sustain the load demanded by the application(s) for steam.

Boiler combustion efficiency generally varies throughout its range and is at a maximum at the higher end of its firing range. Sequence controls maximise efficiency by ensuring that the minimum number of boilers are on-line and that they operate for the longest possible time at the highest firing rates.

Standing losses, radiation losses and other factors also need to be taken into account. For example, at low loads, a boiler may operate with a lower exhaust gas temperature and is a more efficient heat exchanger than at high load points. Digital and intelligent boiler sequencing systems can be configured to take account of more factors (e.g. standing losses, and flow signals from steam meters) than standard sequencing control systems.

Oxygen trim controls

Oxygen trim controls measure the oxygen content in the flue gas stream. This value gives a good indication of combustion efficiency. A signal from the control unit alters the amount of combustion air (via damper or fan speed control) to maintain optimum combustion conditions throughout the firing range, in response to changes in ambient conditions and over time. Oxygen trim controls can be added to a conventional combustion control system or can form an integral part of a digital control system. They can take account of changes in air density as ambient conditions alter, airflow is restricted through filters, etc, but air entering the plant as a result of leakage into ductwork can provide false signals.
The equipment requires regular inspection, cleaning and calibration (particularly the probe as it operates in arduous service conditions).

Hotel benefits from improved combustion control

Installing new burners and controls on the boilers at a major London hotel produced energy savings worth £13,750/year. The total investment cost was £49,720, giving a payback period of 3.6 years.

Full details of this project can be found in **GPCS338 Improving efficiency by renewing boiler burners and controls.** Similar projects could be eligible for an interest-free Action Energy Loan. Call the helpline on 0800 58 57 94 or visit www.actionenergy.org.uk for further information.

Key issues - oxygen trim control

- *Reduce excess air to a practical minimum commensurate with proper combustion of the fuel*
- *Energy savings of up to 2% can be achieved*
- *Suitable for gas-fired and other plant, but its use should be discussed with the burner manufacturer*
- *New equipment may qualify for an enhanced capital allowance (see section 1 and www.eca.gov.uk).*

7 Variable speed drives for combustion air fans

For boilers fitted with fixed speed, forced draught combustion air fans, combustion air control is typically achieved by throttling with an inlet air damper. While simple and reliable, these dampers generally have poor control characteristics at the top and bottom of the boiler's operating range. In addition, the reduction in fan power consumption is small at lower boiler loads, despite lower airflow rates, resulting in higher than necessary electricity consumption. A variable speed drive (VSD) motor can significantly reduce electricity consumption by fans at low loads.

How do VSDs save energy?

Controlling the amount of combustion air delivered to the boiler by a damper adds resistance to flow and reduces the volume delivered; however, the fan speed remains constant. The power consumed by the motor falls as the throttled volume flow decreases and a small power reduction is achieved as the airflow decreases.

The power consumed by a motor is approximately proportional to the cube of fan speed. Therefore, using fan speed as a means of controlling volume flow can generate large electrical power savings. The actual fan characteristics and the drive/motor efficiency will determine the power consumed in any specific installation.

Installing a VSD for the combustion air fan may be economic where the boiler load characteristic is variable. A VSD system reproduces the operating characteristics of a fixed speed combustion air fan and adjustable damper arrangement by controlling the speed of the motor to match the required load under varying process conditions. The use of a VSD system has been shown to be cost-effective while also maintaining good combustion conditions and high boiler efficiency.

Electronic VSDs for combustion air fans (and oxygen trimming) can be fitted as an option with a new burner or as a retrofit to existing equipment.

Energy saving potential

The savings potential is greatest where the load on the boiler is less than the maximum continuous rating for long periods and the burner is required to operate at mid or low fire.

Because electrical power consumption is proportional to the cube of the motor speed, halving the speed reduces the power consumption to around an eighth. The actual savings will depend on the operational requirements of specific installations, but electrical savings in excess of 60% may be possible in some applications.

Key operational considerations – VSDs

- *Help to reduce electrical power consumption significantly at low speed operation*
- *Reduce average noise levels*
- *Provide more flexible control*
- *Improve combustion control on boilers, particularly when used in conjunction with oxygen trim control (see section 6).*

Energy saving potential with VSDs on combustion air fans

- *VSDs can deliver significant savings by matching the performance of the motor to the needs of the process*
- *The extent of savings depends upon boiler operating parameters, but the electrical demand of the fan motor can be reduced by as much as 60%.*

8 Flue shut-off dampers

What does a flue shut-off damper do?

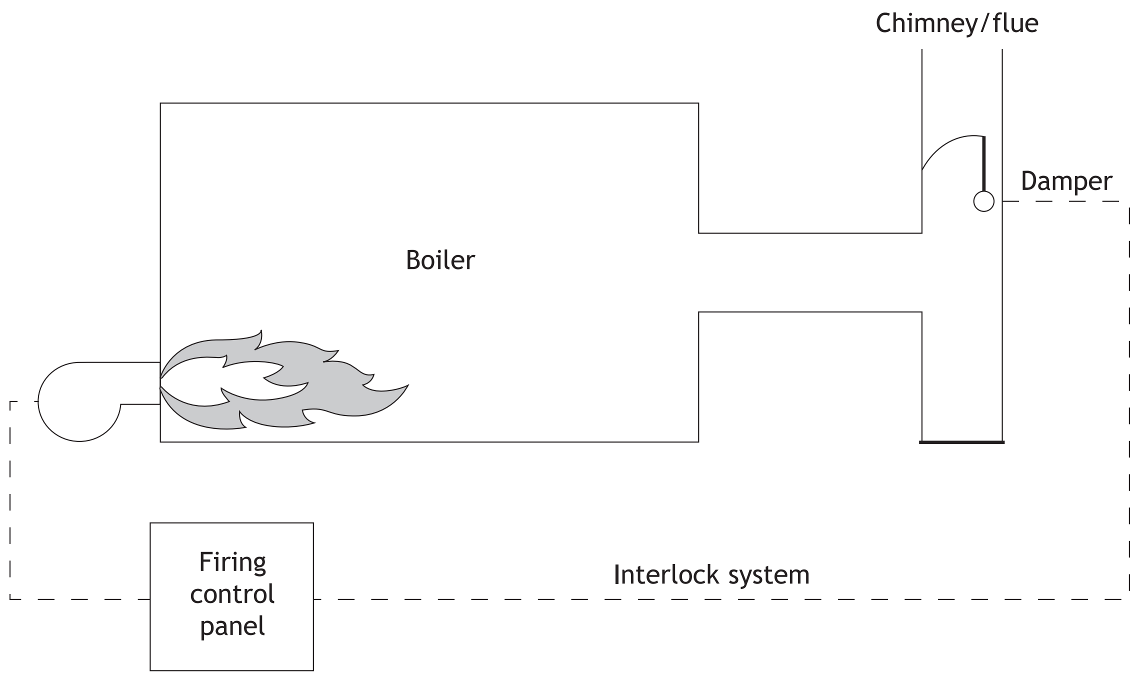
The heat lost from the boiler to the chimney can be significant where boilers are shut down regularly due to load changes. During standby or shutdown, there is a continuous flow of air through the boiler to the flue due to the natural convection resulting from heat transfer from the water. The air in the fire tubes and furnace tubes is heated and this heat is lost via the flue to the outside air.

This section describes the operation and benefits of fitting dampers on flues and on the burner air inlet.

The function of a flue shut-off damper is to prevent heat loss from the flue of a boiler when on standby. Automatic gas-tight shut-off dampers for installation in boiler flues are widely available. A cheaper alternative for forced draught burners (particularly for retrofit situations) is to install an automatic air-sealing damper at the combustion air fan inlet.

An automatic, fully closing damper, fitted either at the flue gas exit or at the burner combustion air fan inlet, closes after any post-combustion purge operation to reduce the ingress of cold air and to prevent air being drawn through the boiler when it is not firing. This reduces system standing losses and prevents excessive fuel being consumed. Figure 8 shows the arrangement of a typical flue shut-off damper installation.

Figure 8 *Schematic of a flue shut-off damper and interlock*



Key operational considerations - dampers

- *Eliminate heat lost from boiler flues when a boiler is on standby*
- *Suitable for all oil and gas-fired boilers*
- *Can be installed by the manufacturer or experienced sub-contractor*
- *Reduce heat losses and emissions of CO_2 and NO_x*
- *Minimal maintenance*
- *In-built safety devices needed that interlock with the burner controls and prevent the boiler firing unless the damper is proven to be in the open position.*

Energy saving potential with flue shut-off dampers

- *Typical savings of 1-2% of fuel input, but can be considerably higher*
- *Payback period is typically two years (depends on the fuel price and boiler utilisation).*

Damper installation

The use of dampers is particularly suited to situations where intermittent, standby or top-up capacity is required, and it is necessary to operate a boiler in standby mode and cycled to keep the pressure/temperature just below the line conditions.

Installation is relatively simple and may be undertaken by either the manufacturer or a suitable contractor. The work involves cutting the flue ducting (if a hot gas damper is chosen), inserting the unit complete with servomotor drive and making the necessary electrical interlock connections.

Safety interlocks are fitted to prevent the burner firing with the damper closed (resulting in the potential build-up of unburnt gas and an explosive mixture in the boiler or a build-up of carbon monoxide in the boiler room). Electrical connections are made from the damper to the appropriate control circuit in the burner panel.

The installation cost is relatively low compared with the savings obtained and this device is ideal for standby boilers and those with cyclic loads. Air inlet sealing dampers can be a more cost-effective option; these are generally smaller and are not exposed to hot and, occasionally dirty, flue gases.

9 Economisers

What is an economiser?

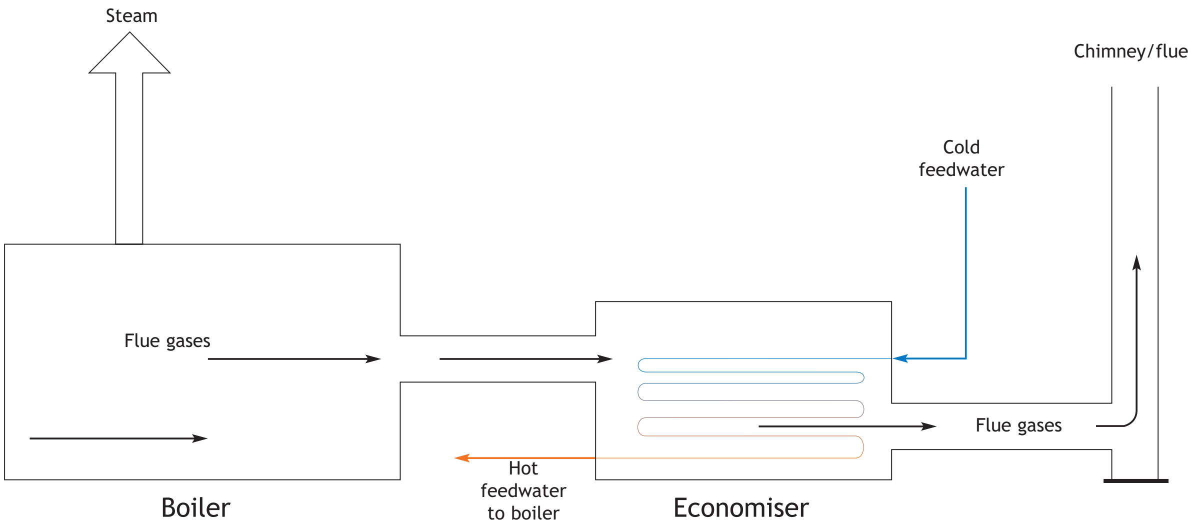
The flue gas from a boiler is at a higher temperature than that of the steam produced and is typically around 200ºC in most modern shell boilers, although the potential for heat recovery is often limited when the combustion gases contain acidic elements (e.g. with coal or oil firing). To prevent the condensation of acid, it is then usually necessary to maintain the exhaust gas temperature to ensure that the dew point of the corrosive gases is not reached.

Economisers are a tried and tested technology for both shell and water tube boilers. An economiser (see Figure 9) is a gas-to-water heat exchanger located within a purpose built flue section. The hot gases exhausted from the boiler are routed through the heat exchanger and around the economiser tubes en route to the stack. Simpler economisers are available that consist of a water jacket fitted around the stack, but these are less efficient.

The most commonly applied function of economisers is to preheat the boiler feedwater before it is introduced into the boiler. The relatively cool feedwater is pumped through the heat exchanger tubes – where it absorbs heat from the hot flue gas exhausted from the boiler – before being pumped into the boiler. During normal boiler operation, the economiser receives a continuous flow of water, corresponding to the boiler steam production.

Condensing economisers use the same principle, but further reduce the flue gas temperature. This improves the boiler system efficiency.

***Figure 9** Schematic of an economiser*



Uses of economisers

In steam boilers, where a substantial proportion of the condensate is returned to the boiler feed tank, the boiler feedwater may be at a relatively high temperature. Under such circumstances, the potential increase in temperature available from the economiser will decrease and the increase in efficiency will, therefore, be minimal.

It is important to use the correct size of economiser. If too much heat is transferred to the feedwater, it may exceed the acceptable operating temperature for the system or it may be flashed off to steam.

The fitting of economisers therefore requires careful financial and technical consideration. Attention should be given to the additional controls and bypasses required for varying load and fuels, the risk of potential problems with the flue gas flow, and the possibility of damage to the stack.

Economisers are best suited to larger gas-fired boiler plant; it is generally considered uneconomic to install an economiser to recover heat from boilers burning other fuels. With dual-fuel (gas and oil) burners, the economiser is normally bypassed when firing oil to avoid corrosion due to the flue gas temperature falling below the dew point.

Economiser installation involves:

- Locating the heat exchange unit in the flue section
- Diverting the feedwater pipework to and from the unit
- Wiring to the bypass damper limit switches (if necessary)
- Fitting water and flue gas thermometers (to establish performance).

Depending upon the size of the boiler, economisers can be quite large. It is therefore necessary to consider the space available within the boiler room at the boiler flue outlet. The boiler feedwater pump may also have to pump water at a higher temperature.

Energy saving potential with economisers

- *Significant savings of typically 3-5% of fuel input*
- *Payback usually exceeds two years, but will depend on boiler loading*
- *Enhanced capital allowances may be available for fitting flue gas economisers to boilers (see section 1 and www.eca.gov.uk).*

Key operational considerations – economisers

- *Some of the heat lost in the exhaust gases can be recovered (particularly from gas-fired boilers)*
- *Gas and dual-fuel-fired boilers are ideally suited to this energy efficiency measure*
- *Suitable for shell and water tube boilers rated above 2MW*
- *Installation by boiler/burner manufacturer or mechanical engineering contractor specialising in economisers*
- *Consult burner/boiler maker for technical information*
- *Maintenance requirements are similar to a boiler.*

Energy savings potential

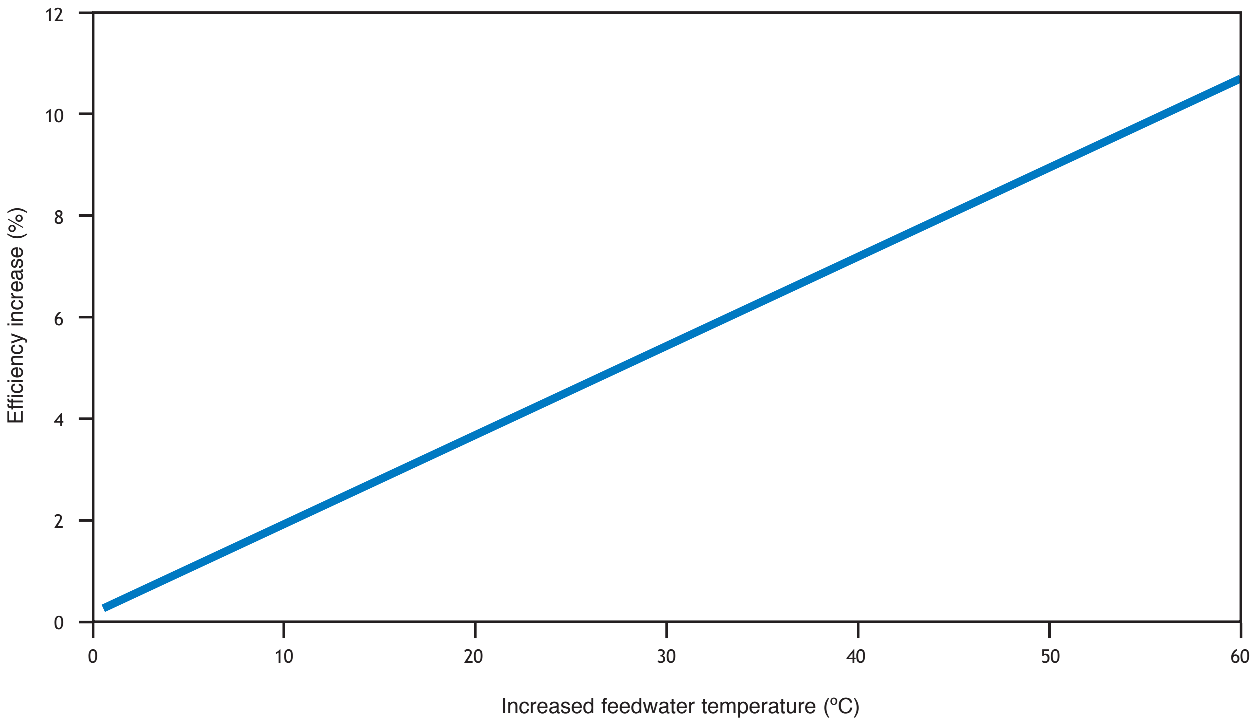
The potential energy efficiency improvement depends on both the boiler type and the fuel used.

For an older shell boiler where flue gas temperature may be around 260ºC, an economiser could typically reduce this temperature to around 200ºC and increase the feedwater temperature by around 15ºC. This would raise the overall boiler efficiency by approximately three percentage points.

In a modern three-pass shell natural gas-fired boiler with a flue gas temperature of around 140ºC, a condensing economiser could reduce this temperature to around 65ºC. This would increase the boiler efficiency by approximately five percentage points.

Figure 10 shows the overall boiler efficiency increase available through using heat from the flue gases to preheat the boiler feedwater. Generally, for every 1ºC increase in boiler feedwater temperature, there is a drop of approximately 4ºC in flue gas temperature. For example, if the feedwater temperature was increased by 30ºC then, for a similar evaporation rate, the fuel saving would be approximately five percentage points; alternatively, the boiler output would rise by a similar amount.

Figure 10 *Effect of feedwater preheating on boiler efficiency*



10 Combustion air preheating

What is combustion air preheating?

Burners require air to combust the fuel. This air is generally taken from within the boiler room, either assisted by a fan in a forced draught burner or unassisted in the case of a natural draught burner. This incoming combustion air, which is at boiler room temperature, has the effect of cooling within the boiler itself. Boiler efficiency can be improved by preheating the incoming combustion air; this reduces the cooling effect and provides a higher flame temperature from the burner.

Types of combustion air preheating

The usual heat sources for combustion air preheating are:

- Heat remaining in the flue gases
- Higher temperature air drawn from the top of the boilerhouse
- Heat recovered by drawing over or through the boiler casing to reduce shell losses.

Using the heat remaining in the flue gases is expensive and requires a stainless steel plate type heat exchanger fitted in the boiler flue system. It is also necessary to fit bypass dampers when firing fuel oil instead of natural gas. In addition, the forced draught fans must be capable of overcoming the additional backpressure.

Most gas and oil burners used on boiler plant were not originally designed for high preheat temperatures and a maximum increase of 50ºC is usually all that can be tolerated. Modern burners are available that can stand much higher temperatures. It is therefore possible to consider installing a heat exchanger in the exit flue as an alternative to an economiser, although combustion air preheaters are larger and less efficient overall for preheating boiler feedwater.

Exhaust gas recirculation

Burner manufacturers now supply a range of low-NO_x burners, for both cold-air and hot-air firing. The burners incorporate a number of special features (usually including carefully staged combustion and partial fuel premixing) and have been shown to reduce NO_x emissions significantly.

Although more commonly used in furnace applications, self-recuperative burners have been developed that are equipped with an eductor to draw hot waste gases from the flue or chimney through an inbuilt recuperator and preheat the incoming cold combustion air. A separate recirculating fan can also be used, but flue gas recirculation is generally considered a pollution control measure rather than an energy efficiency measure.

Key operational considerations – combustion air preheating

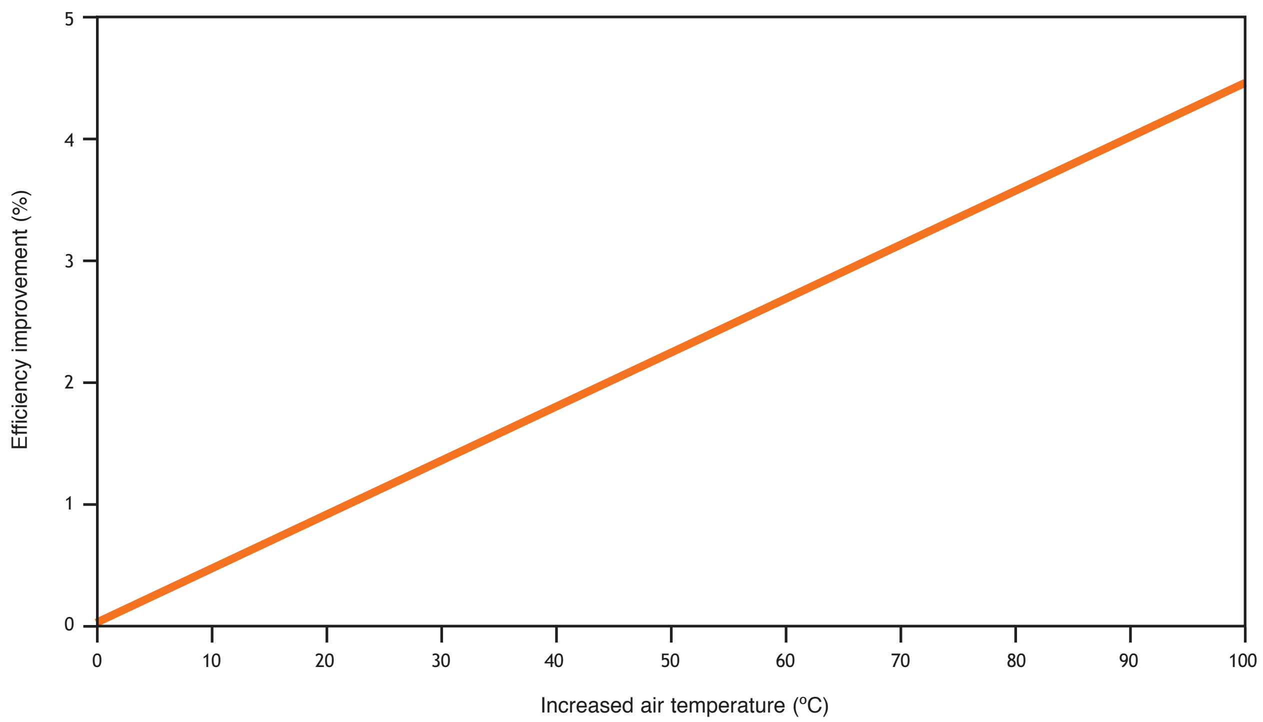
- *Enables hot ambient air in the roof space of the boilerhouse to be used as combustion air*
- *Generally suitable for larger boilers*
- *Appropriate equipment can be installed by a local sheet metal fabricator*
- *Requires relatively little maintenance.*

Energy saving potential

Boiler efficiency can be increased by one percentage point by raising the combustion air temperature by 20ºC. The savings will depend upon the type of system installed. Figure 11 shows the potential efficiency improvements available.

Ducting hot air down from the top of the boilerhouse will typically provide savings of up to 1%, while drawing combustion air over or through the boiler casing can provide savings of up to 2%.

Figure 11 *Effect of air preheating on boiler efficiency*



Energy saving potential with combustion air preheating

- *Savings of 1-2% can be achieved (these are also energy savings if you want to be consistent with previous comments)*
- *Payback period is typically less than three years.*

Other sources of information

Action Energy publications

The following free Action Energy publications can be obtained by calling the helpline on 0800 58 57 94 or visiting www.actionenergy.org.uk.

- GPG002 Guidance notes for reducing energy consumption of electric motors and drives
- GPG018 Reducing consumption costs by steam metering
- GPG088 Energy efficient use of boilers using chain grate stokers
- GPG217 Cutting energy losses through effective maintenance (totally productive operations)
- GPG221 Improving boiler energy efficiency through water treatment
- GPG252 Burners and their controls
- GPCS338 Improving efficiency by renewing boiler burners and controls
- GPCS339 Heat recovery from boiler blowdown
- GPCS382 Energy and cost savings in hot water boilers through the use of isolation dampers
- ECG066 Steam generation costs
- ECG092 Steam distribution costs
- FEB002 Steam
- FEB014 Economic use of oil-fired boiler plant
- FEB015 Economic use of gas-fired boiler plant
- FEB017 Economic use of coal-fired boiler plant
- NPFP059 Condensing economiser on a gas fired steam boiler
- FL0069b Everyone's guide to energy efficiency through effective maintenance

Further reading

- BS845:1987 Methods for assessing thermal performance of boilers for steam, hot water and high temperature fluids
- BS2486:1997 Recommendation for treatment of water for steam boilers and water heaters
- Health and Safety Executive (HSE) Plant and Machinery Guidance Note PM5 Automatically controlled steam and hot water boilers
- Health and Safety Executive (HSE) Plant and Machinery Guidance Note Guidance Note PM60 Steam boiler blowdown systems
- Pressure Systems Safety Regulations 2000 (SI 2000/128) (can be downloaded from www.hmso.gov.uk)
- Control of Substances Hazardous to Health Regulations 2002 (SI 2002/2677) (can be downloaded from www.hmso.gov.uk)
- BetzDearborn handbook of industrial water conditioning. 9th edn. ISBN 0913641006. Betz Laboratories (1991)
- CADDET. Steam production and distribution. Maxi Brochure 13 (March 2001) (can be downloaded from www.caddet.org)
- Combustion Engineering Association (CEA) A guide to steam plant operation (August 1999) (can be downloaded from www.cea.org.uk)
- Gunn D and Horton R. Industrial boilers. Longman Scientific and Technical (1989)[2]
- Kemmer FN (ed.) The NALCO water handbook. 2nd edn. ISBN 0070458723. Nalco Chemical Company/McGraw-Hill (1988)
- Kitto JB and Stultz SC (eds) Steam: its generation and use. 40th edn. ISBN 0963457004. Babcock & Wilcox Co. (1992)
- Spirax Sarco free on-line learning modules, accessed at www.spiraxsarco.com/learn.

[2] Currently out of print; however, it can be borrowed from the British Library Document Supply Centre and other academic libraries.

Glossary

Blowdown	High-pressure water at the steam saturation temperature that is released from a steam boiler to control water quality.
Combustion	A rapid chemical reaction between the combustibles in the fuel and oxygen in the air with liberation of heat. In gas and liquid fuels, carbon and hydrogen constitute the combustibles.
Combustion air	Air that contains the oxygen needed to burn the fuel. Identified as either primary air (introduced at the point of combustion) or secondary or tertiary air (introduced to the flame).
Combustion efficiency	The percentage of heat released that is put to use compared with the total heat energy in the fuel.
Condensate	The pure water formed as steam condenses.
Convection	Heat transfer that occurs between a surface and a moving fluid when they are at a different temperature.
Dry steam	Steam containing no water droplets.
Excess air	The provision of combustion air in greater quantities than is required to provide sufficient oxygen for stoichiometric combustion.
Flash steam	The steam produced when the pressure of hot condensate is reduced.
Gross (higher) calorific value	The quantity of heat liberated when a fuel is burned, including the heat liberated when water vapour condenses to liquid at room temperature.
Net (lower) calorific value	The quantity of heat liberated when, under practical considerations, the combustion gases are not cooled sufficiently to liberate the latent heat of water.
Priming	An extreme case of carryover where significant amounts of boiler water get into the steam pipework.
Steam separators or dryers	Devices to remove the entrained water droplets from wet steam.
Total dissolved solids (TDS)	The quantity of solids dissolved in a known volume of water.
Wet steam	A mixture of steam and water droplets.

Appendix – Example calculations for a natural gas-fired boiler

This appendix features a natural gas-fired boiler, and illustrates:

- *The significant potential for energy and carbon savings from taking action to improve boiler efficiency, applicable to all fuel sources*
- *The effect on flue gas losses of increasing and reducing excess air*
- *The effect on flue gas losses of increasing flue gas temperature.*

Table A1 gives operational details for the example boiler.

Table A1 Boiler operational details

Parameter	Value
Flue gas losses	18%
Radiation losses	2%
Blowdown loss	3%
Other losses	2%
Boiler efficiency	75%
Flue gas temperature	195°C (383°F)
Feedwater temperature	15.5°C (60°F)
Return temperature	Assumes mains water at 8°C (47°F) and 25% condensate return at 38°C (100°F)
Steam production (approx)	1.08kg/s (8,000lb/hour); 7,000 hours/year
Steam pressure	7barg (100psig)
Steam temperature	170°C (338°F) (dry saturated)
Fuel energy input	26,102MWh/year
Carbon dioxide released	4,959 tonnes/year

Calculating the effect of changes in boiler efficiency

The possible savings or losses due to changes in boiler efficiency are revealed by a simple calculation.

Change in energy consumption =

$$\text{Original energy consumption} \times \frac{(\text{New boiler efficiency} - \text{Original boiler efficiency})}{\text{New boiler efficiency}}$$

If the efficiency of the example boiler is increased from 75% to 76%:

$$\text{Annual energy saving} = 26{,}102\text{MWh} \times \frac{(76 - 75)}{76} = 343.4\text{MWh}$$

The equivalent carbon saving (in kg) is obtained by multiplying the energy saved (in kWh) by the appropriate conversion factor.

Annual carbon saving = 343.4 x 1,000 x 0.19 = 65,246kg = 65.25 tonnes

Calculating the effect of reduction and increase in excess air

Figure 7 in section 6 provides a reference chart for estimation of flue gas losses (natural gas) that is sufficiently accurate for the aims of this publication. If more accurate estimates are required then equations, such as those contained in BS845: 1987 (Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids), should be used.

Figure 12 provides an illustration of both a reduction and an increase in excess air over the original conditions for the example boiler details given in Table A1. Figure 12 represents three conditions of excess air at the same flue gas temperature.

Reference condition

In the example boiler, the reference operating conditions were 9.75% carbon dioxide at a flue gas temperature of 195˚C. This equates to 20% excess air and a flue gas loss of 18%.

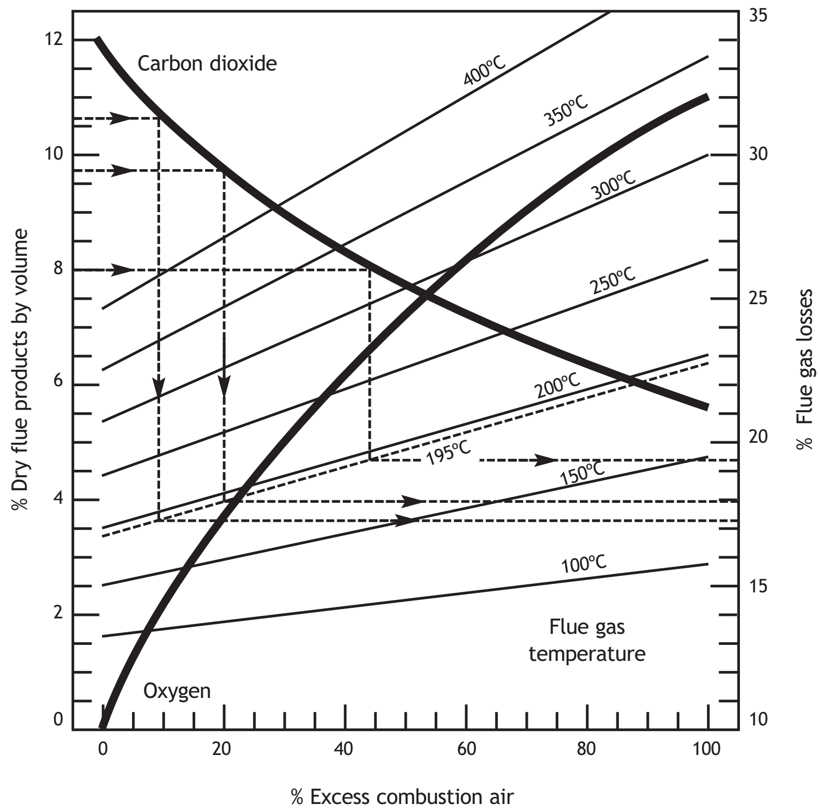
Reduction in excess air from reference condition

In the example boiler the reference operating conditions are changed to 10% excess air and this would result in 10.7% carbon dioxide at a flue gas temperature of 195˚C. This equates to a flue gas loss of 17.4%.

Increase in excess air from reference condition

In the example boiler the reference operating conditions are changed to 44% excess air and this would result in 8% carbon dioxide at a flue gas temperature of 195˚C. This equates to a flue gas loss of 19.3%.

***Figure 12** Effect of reduction and increase in excess air on flue gas losses (natural gas)*



Calculating the effect of higher flue gas temperatures

Figure 7 in section 6 provides a reference chart for estimation of flue gas losses (natural gas) that is sufficiently accurate for the aims of this publication. If more accurate estimates are required then equations, such as those contained in BS845: 1987 (Methods for assessing thermal performance of boilers for steam, hot water and high temperature heat transfer fluids), should be used.

Figure 13 provides an illustration of an increase in flue gas temperature over the original conditions for the example boiler details given in Table A1. Figure 13 represents two conditions of flue gas temperature as follows:

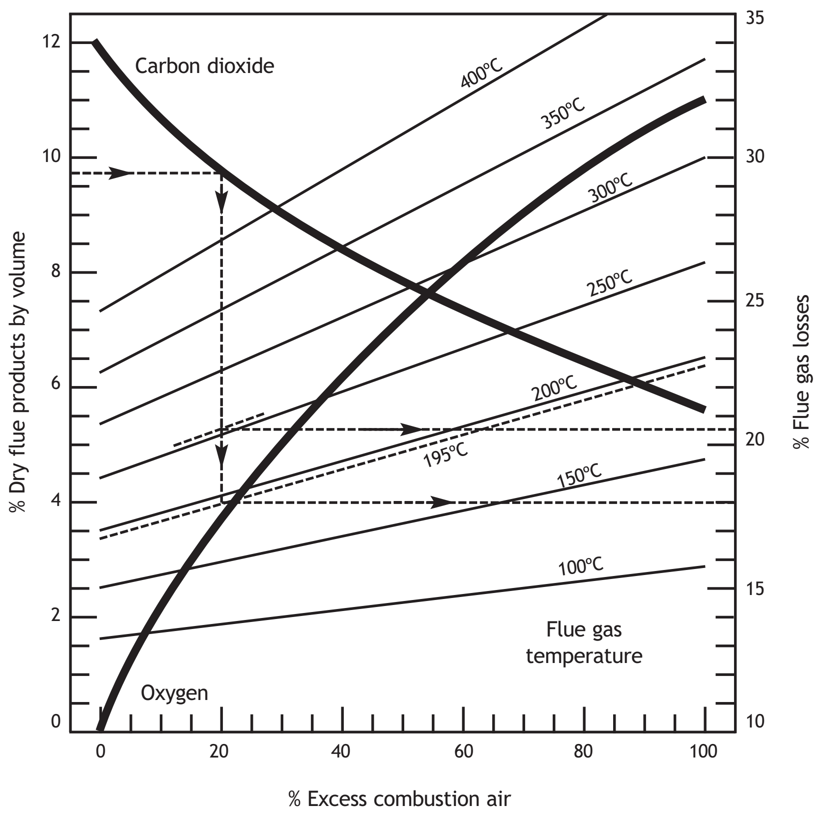
Reference condition

In the example boiler the reference operating conditions were 9.75% carbon dioxide at a flue gas temperature of 195ºC. This equates to 20% excess air and a flue gas loss of 18%.

Increase in flue gas temperature from reference condition

In the example boiler the reference operating conditions are changed to a flue gas temperature of 251ºC with the same excess air and flue gas composition. This equates to a flue gas loss of 20.5%.

Figure 13 Effect of higher flue gas temperature on flue gas losses (natural gas)



Free Money

Unbelievable?

It's true. Action Energy Loans are designed to make you money when you replace your equipment with more energy-efficient kit. Thanks to government funding, SMEs can borrow £5,000 to £50,000 at 0% interest. Even better, your energy savings may more than cover your loan repayments, so you could make free money from day one.

Here's an example of the savings Tough Glass have made:

Loan awarded	£28,359	SAVINGS
Energy bill savings p.a.	£45,000	
Annual repayment amount	£14,179	
Annual savings during loan period		**£30,821**
Annual savings after loan repaid		**£45,000**

"Getting an Action Energy Loan has made a real difference to our bottom line. Not only will the savings we make cover the cost of the loan repayments, but will actually add to our company profits."

Peter O'Hara, Managing Director, Tough Glass

Find out more. Call or visit:

0800 58 57 94

www.actionenergy.org.uk/getaloan

Call today and receive a **FREE** Business Starter Pack

ACTIONenergy
From the Carbon Trust

Tel 0800 58 57 94

www.actionenergy.org.uk

Action Energy is a programme run by the Carbon Trust and funded by
the Department for Environment, Food and Rural Affairs, the Scottish Executive,
Invest Northern Ireland and the National Assembly for Wales.

Action Energy is a programme run by the Carbon Trust. The Carbon Trust is a company limited by guarantee. Registered in England and Wales Number 4190230. Registered at: 9th Floor, 3 Clement's Inn, London WC2A 2AZ